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## DEVELOPMENT OF A SUSTAINABLE ENGINEERING MASTERS PROGRAM: THE PATH TAKEN AND LESSONS LEARNED

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**Abstract:** Beginning in 2002, the Kate Gleason College of Engineering (KGCoe) at the Rochester Institute of Technology (RIT) began implementing a series of sustainability themed curricular innovations. These innovations began in 2002 with the introduction of courses focused on sustainability, followed with the implementation of a programmatic minor in Sustainable Product Development in 2006, and culminated with the development and registration of the nation's first Sustainable Engineering graduate programs in 2008. This article describes the genesis and maturation of KGCoe's Sustainable Engineering graduate programs. The article reviews the early work that set the stage for the development of the new degree programs in Sustainable Engineering, and details the establishment and workings of the multidisciplinary faculty team that was charged with structuring the programs and marshalling them through the RIT curricular approval process and the New York State program registration process. These award winning programs have now been in place for over 7 years, and during that period they have evolved. This article describes the lessons learned along the program development path and highlights important program outcomes. Particular attention and reflection is devoted to the unusual demographic characteristics of the graduate student body that constitutes the programs. A comparison between the populations of these programs in sustainable engineering and those from other engineering departments in the same college is presented. The results indicate that the Sustainable Engineering programs are attracting a more diverse pool of students (with respect to academic preparation, national origin, and gender) than other KGCoe graduate programs.

### 1 INTRODUCTION

Efforts to reform engineering education over the past two decades have met with limited success. Although some engineering programs have effectively addressed a new vision for engineering pedagogy, the National Academy of Sciences (1997) and the National Research Council (2003, 1999) have identified several problematic attributes in engineering education. In particular, engineering programs have been criticized for their inability to effectively integrate multiple engineering and non-engineering disciplines in solving today's complex science and technology problems. Nowhere is the appreciation of the technical and non-technical aspects of the engineering field more appropriate than in problem domains related to "sustainability".

Interest in sustainability and related issues continues to grow nationally as well as internationally. A sustainable economy is one that can meet the needs of the present without compromising the ability of future generations to meet their own needs (UNWCED, 1987). Moving an economy toward the goal of sustainability presents myriad challenges for all professions, especially business and engineering. As we move forward in the 21<sup>st</sup> century, the problems associated with delivering society's goods and services using traditional, non-sustainable practices will become more apparent, and the value of more

environmentally and socially responsible approaches to meeting society's needs will become increasingly evident. Engineers and managers must be equipped to become environmental leaders and decision makers.

Toward this end, college curricula that address product and process development will need to change in order to equip engineers and business leaders with the modern tools they will need to meet the challenge of delivering goods and services through sustainable means. This notion is reinforced by the inclusion of knowledge about sustainability as one of the core criteria that engineering programs must demonstrate their students attain in order to earn accreditation by the Accreditation Board for Engineering and Technology:

Engineering programs must "have documented student outcomes that prepare graduates to attain... an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability and sustainability" (ABET, 2015)"

The Kate Gleason College of Engineering (KGCOE) at the Rochester Institute of Technology (RIT) has about 3400 students enrolled in its nine engineering programs. In recent years the college has seen significant innovative curricular efforts in the areas of sustainability and sustainable engineering that span across multiple disciplines and departments. These include topical courses and senior design projects, programmatic minors as well as masters programs. Some of these innovations have been motivated by faculty directly involved in this area, others by students interested in working in the area of sustainability. This article focuses on the development of two Master's level programs in Sustainable Engineering, the interdisciplinary curricula that comprises them, lessons learned along the program development path, and some specific program outcomes.

## 2 BACKGROUND

At RIT, the motivation to develop sustainability themed curricula may well have originated from within the student body. Some of the earliest sustainability oriented work in the KGCOE was undertaken by graduate students in the Mechanical Engineering (ME) and the Industrial and Systems Engineering (ISE) departments completing their graduate research theses. Typically, these thesis projects involved the application of traditional optimization or analysis techniques to problem domains with environmental themes. Early examples include:

- evaluating the use of product architecture to improve environmental performance (Sciortino, 1999)
- using statistical methods to model the performance of pollution control equipment (Wuotinen, 2003)
- evaluating the role of remanufacturing products to reduce environmental impacts (Mariano, 2005)
- examining the relationship between focused factory manufacturing strategy and environmental performance (Hurst, 2005)

Given the level of interest demonstrated by students at the time, it became clear to the faculty and the administration of KGCOE that development of additional courses and programs with sustainability themes was warranted. Subsequent initiatives included:

- creation of a number of new courses with sustainability themes (i.e. "Fundamentals of Sustainable Engineering", "Lifecycle Assessment", "Design for the Environment")
- establishment of a student chapter of a sustainability oriented professional society in KGCOE (Engineers for a Sustainable World; <http://www.eswusa.org/>)
- development of a programmatic minor in Sustainable Product Development (Carrano and Thorn, 2007, 2005; Thorn and Carrano, 2006;)

When the Sustainable Product Development (SPD) minor was established at RIT, program minors consisted of 5 four credit courses totalling 20 credit hours (RIT has since transitioned to a semester system and current minors require 5 three credit hour courses totalling 15 credit hours). The SPD minor is aimed at students interested in exploring issues associated with developing and delivering sustainable product systems. Courses in the minor address each of the three dimensions of sustainability (economic, ethical, environmental), develop awareness of the need for more sustainable approaches to product development, and explore strategies for developing and delivering sustainable product systems.

The minor is administered through the ISE department, but it is structured to offer a multidisciplinary experience. Three core courses from the ISE department are required: Engineering Economics, Fundamentals of Sustainable Engineering, and Lifecycle Assessment. Of the remaining two courses, at least one must be taken from a list of available “Social Context” electives. The Social Context electives include offerings from RIT’s College of Business (i.e. “Corporate Social Responsibility and Business Ethics”, “Managing for Environmental Sustainability”) and its College of Liberal Arts (i.e. “Energy Policy”, “Engineering and Public Policy”).

During its first year of availability the SPD minor attracted 6 undergraduate students, all engineering majors. This was more than any of the other ISE minors. At the time, this was considered quite remarkable since the minor was new and had not been well advertised. Since its establishment, the minor has continued to attract new students (4-6 per year) but the range of participants has expanded from engineering majors to include students from Industrial Design, Environmental Science, Architecture, Manufacturing Technology, and Packaging Science.

### **3 DEVELOPMENT OF SUSTAINABLE ENGINEERING GRADUATE PROGRAMS**

Given continued student interest in sustainability themed engineering education and continued course development to support those interests, the leadership of KGCOE determined that it would be appropriate to introduce graduate level programs to help equip technically oriented students with the tools they need to meet the challenges associated with delivering goods, energy, and services through sustainable means. Development of the new programs began using the tentative title of “Sustainable Engineering”. Program development began in September, 2006. The two proposed programs completed the RIT curricular approval process in May, 2007. Subsequently, the programs were reviewed and approved by the New York State Education Department. Students were first able to enrol in the programs fall, 2008.

#### **3.1 Program Development Process**

A multidisciplinary team of faculty was assembled to develop the new graduate program/programs. The team included representatives from RIT’s College of Engineering, College of Applied Science and Technology, College of Business, and College of Liberal Arts. This team was charged with specifying the type of degree program or programs that would be offered, establishing the curricular content for the proposed program(s), marshalling the program proposal(s) through RIT’s curricular approval process, and preparing the materials required for program approval and registration with the New York State Education Department.

The team proposed two degree programs: a Master of Science degree program (MS) and a Master of Engineering degree program (MEng). The MS degree is a research oriented degree and concludes with the development and defense of a formal research thesis. The MEng program does not require a research thesis but, rather, emphasizes additional coursework requirements and the completion of an application-based project.

#### **3.2 Program Structure**

The two Sustainable Engineering graduate programs have similar curricular structures. Figure 1 shows the structure of the MS program while that of the MEng program is displayed in Figure 2. The programs were originally delivered via an academic calendar based on quarters, but RIT has since transitioned to a

semester system. The figures show both the original, quarter based credit hour counts and the current semester credit hour counts. Both programs rely on a core of 5 required courses from the College of Engineering (COE), an elective set of courses from COE, an elective set of courses taken external to COE, and a summary experience. For the MS program the summary experience is a formal research thesis, while the MEng program concludes with the completion of an applied capstone project. The MS program also requires that students participate for one academic year in the ISE department's Graduate Seminar.

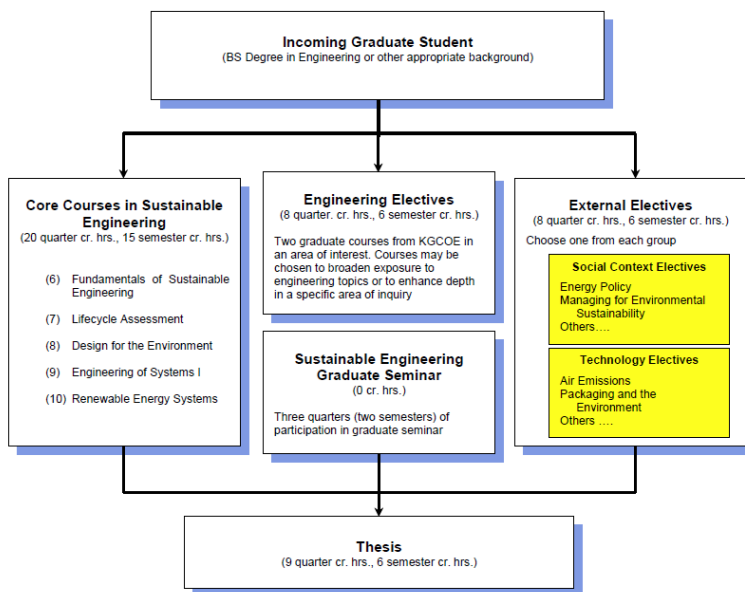


Figure 1: Curriculum structure for the M.S. in Sustainable Engineering program

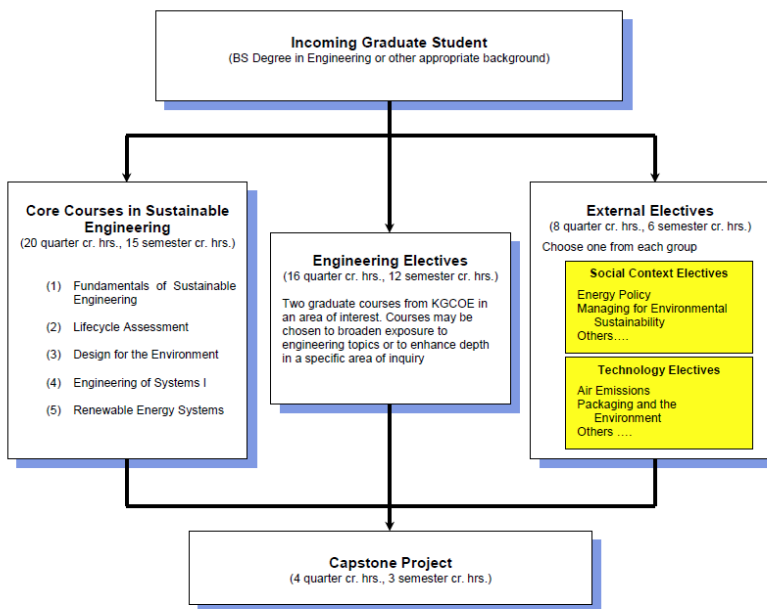


Figure 2: Curriculum structure for the MEng. in Sustainable Engineering program

Initially, under the quarter based academic calendar, the MS program could be completed in two academic years (6 quarters) and the MEng program could be completed in one (3 quarters). Under the current semester system the MS program requires two academic years (4 semesters) while the MEng program requires 1 ½ years (3 semesters).

### 3.3 Program Administration

Since the Sustainable Engineering degree programs are technical in nature and because the word “engineering” appears in the name of the degree, it was clear from the outset that the programs would be housed in the College of Engineering. However, within RIT’s COE there are a number of models for graduate program administration. Some (like the MS program in Industrial and Systems Engineering) are administered at the departmental level while others (like the Ph.D. program in Engineering) are administered at the college level. Because the ISE faculty had provided the impetus for developing the SE programs and because the ISE department was responsible for delivering much of the required content for the programs, the Dean of the college chose to locate the SE graduate programs in the ISE department. The Sustainable Engineering programs thus became one of three graduate programs located in the ISE department. Figure 3 offers a simplified organizational chart depicting the administrative location of the SE graduate programs.

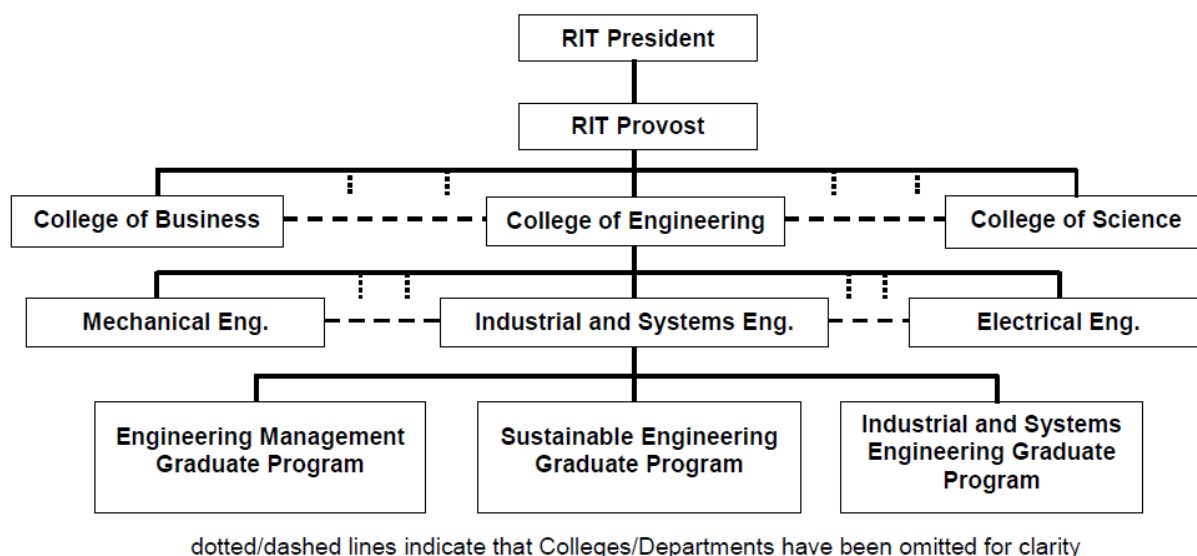


Figure 3: Simplified Organization Chart Showing S.E. Program Location

## 4 PROGRAM DEMOGRAPHIC DATA

A major concern raised during RIT’s program review process was that the proposed Sustainable Engineering programs would not attract new graduate students, they would merely spread out students who would have pursued a graduate engineering degree at RIT anyway among a larger set of masters degree offerings. The Sustainable Engineering graduate programs are housed within the Industrial and Systems Engineering department in the College of Engineering. Here we compare student demographic data from the SE program to similar data from other COE graduate programs (the MS/MEng programs in Mechanical Engineering (MechE), the MS/MEng programs in ISE, and the MEng program in Engineering Management) can be used to examine this claim. The Office of Institutional Research and Policy Studies at RIT provided student demographic data for each of the ISE and SE graduate programs for academic years 2009-2014, and data from the Mechanical Engineering graduate programs for academic years 2012-2014. Table 1 provides the data from the non - Sustainable Engineering programs, while Table 2 displays the data for the Sustainable Engineering programs. Note that the RIT system does not generate

demographic data for programs with headcounts below 4. Where this occurs in Tables 1 and 2, “n/a” (not available) is entered.

**Table 1: Demographic Data for non-SE Programs**

Year (20__)	ISE ME						ISE MS						ENGMGMT ME						Mech E (MS/MEng)		
	9	10	11	12	13	14	9	10	11	12	13	14	9	10	11	12	13	14	12	13	14
Headcount	7	1	10	12	6	10	27	31	28	32	36	41	20	16	22	20	26	13	39	40	56
Female%	42.9	n/a	10.0	16.7	33.0	10.0	18.5	25.8	14.3	15.6	8.3	7.3	40.0	56.3	50.0	45.0	50.0	46.0	7.7	10.0	12.5
International%	85.7	n/a	90.0	83.3	100	100	92.6	90.3	96.4	93.8	94.4	92.7	85.0	75.0	72.7	75.0	73.1	76.9	79.5	67.5	82.1

**Table 2: Demographic Data for SE Programs**

Year (20__)	SE ME						SE MS					
	9	10	11	12	13	14	9	10	11	12	13	14
Headcount	1	3	6	10	1	2	1	3	6	10	10	11
Female%	n/a	n/a	33.3	60.0	n/a	n/a	n/a	n/a	33.3	40.0	40.0	63.6
International%	n/a	n/a	33.3	80.0	n/a	n/a	n/a	n/a	33.3	30.0	30.0	27.3

The SE programs appear to attract a different group of students than the other four programs. The most striking difference is with respect to the percentage of international students enrolled in the programs which is consistently lower than the proportions enrolled in the MechE, the ISE, and the Engineering Management programs. Clearly the SE programs are attracting a higher proportion of domestic students than the other programs.

In addition, it is clear that the Engineering Management and the Sustainable Engineering programs are attracting a higher percentage of female students than the MechE and the ISE graduate programs. The SE and Engineering Management programs offer broader coursework than the MechE and ISE programs, which are more discipline specific. Recall that the SE programs require that students select courses from outside the College of Engineering. The Engineering Management program at RIT is interdisciplinary in that it is comprised of courses from the ISE department and management courses from RIT's College of Business.

Both the ISE MS and SE MS degree programs are research oriented and require the defense of a formal research thesis. Comparing the data from these two programs provides a clear contrast. The percentage of female students enrolled in the SE MS program ranges from 33%-64%, and the percentage of domestic students varies from 67%-73% for the years where data is available. For the ISE MS program the percentage of females varies from 7%-25% and the percentage of domestic students ranges from 4%-10%. The MS program in SE appears to attract a much higher percentage of female and domestic students than the ISE MS program.

The SE program may also be attracting students with a broader range of undergraduate experience than the ISE and Engineering Management programs. While RIT does not record data on the undergraduate degrees of its graduate student population, anecdotal evidence suggests that the students enrolled in the ISE and Engineering Management programs tend to come from undergraduate engineering backgrounds, usually Industrial Engineering or a variant. The current roster of Sustainable Engineering students shows students from Industrial Engineering, Chemical Engineering, Civil Engineering, Mechanical Engineering Technology, Biology, Physics, and Environmental Science.

## **5 LESSONS LEARNED**

### **5.1 Program Development**

At RIT, the Sustainable Engineering domain was not treated as a unitary discipline. Rather, the underlying premise was that problems with sustainability themes will need to be addressed by individuals with a range of backgrounds and preparation. So, at RIT, the SE curriculum is not delivered through a single centralised SE department. Instead, the SE graduate programs rely, in large part, on courses that are delivered by faculty from a range of disciplines and academic departments. The SE programs were developed by a team of faculty drawn from disciplines spanning at least 4 of RIT's colleges. This multidisciplinary approach was absolutely crucial to ensure coverage of the economic, environmental, and ethical dimensions of sustainable engineering, and to secure eventual buy in and program approval.

### **5.2 Program Structure**

The SE programs rely on a core set of five required engineering courses, a set of two (or four depending on the degree) student selected engineering electives, and two student selected non-engineering electives. The programs conclude with either an applied capstone project or a formal research thesis. Compared to other graduate engineering programs the SE program is very flexible, offering students the opportunity to choose a substantial portion of their coursework (44% for the MS program and 50% for the MEng program). This flexibility enables students to deepen their understanding of topics that are of special interest by selecting additional courses in a specific area, or they can broaden their exposure to other topics or enhance their technical toolkit by opting for different courses. Because the SE programs utilize courses from many academic departments, the flexibility of the programs grows as these other departments add courses to their portfolios. The SE graduate students appreciate this flexibility, and have been very proactive in scouring RIT's course catalog for the coursework that matches their interests.

### **5.3 Program Administration**

As described earlier, RIT's administration chose to house the SE graduate programs within the ISE department. This choice was expedient and was made primarily because ISE faculty led the development efforts and much of the required content of the SE programs was delivered through ISE. Some unanticipated consequences have arisen from this choice.

The original intent was that the SE graduate programs would be College of Engineering programs, and that all departments in the College would participate. However, with the programs located in the ISE department and with much of the program content delivered by ISE faculty, participation from other departments has been limited. Because four of the five required courses for the SE programs are ISE courses, the SE graduate students are guaranteed exposure to ISE faculty. Additionally, many of the ISE graduate courses are popular choices as SE engineering electives. SE students have reported that it is difficult establishing relationships with faculty from non-ISE programs in the one or two semesters available before they have to develop a thesis topic. As a result, virtually all of the SE graduate theses and all of the SE graduate capstone projects originate in the ISE department and are advised by ISE faculty. This is a concern for at least two reasons:

- students who are interested in pursuing thesis topics or capstone projects that could be best advised by non-ISE faculty are not being served as well as they should be
- faculty from non-ISE programs who are pursuing sustainability oriented research projects may not be aware of the talent available in the SE graduate student body

A number of strategies for addressing this issue are currently under consideration. One option is to make an effort to expand the topics discussed in the senior seminar series and to encourage interested faculty from other programs to describe their research work and solicit students. A related tactic would be to encourage student attendance (and perhaps reward it) in the graduate seminars of other departments. Another approach would be to administer the program and fund SE students at the College level instead of at the Departmental level. This strategy could essentially turn the SE graduate students into a College resource rather than a Departmental one.



## 5.5 Program Demographics

As noted earlier, during the development of the SE programs, there was a good deal of concern about the sort of students that the programs would attract. At issue was whether the programs would attract new students specifically interested in this emerging discipline of SE or merely divert students who would have entered one of RIT's graduate engineering programs anyway.

The data available to date suggests that the SE programs are indeed attracting new students to RIT's College of Engineering. Students in the SE cohort exhibit a broader range of academic backgrounds than students in other ISE graduate programs and are more likely to come from US undergraduate programs. In addition, the SE programs have attracted a very high percentage of female students, especially when compared to the other MS thesis based degree program offered by the ISE department.

## 6 CONCLUSIONS

RIT's Sustainable Engineering graduate programs have been operating since 2008. It appears that these programs are attracting students who would not be attracted to the more traditional engineering graduate programs available within the MechE and ISE departments at RIT. Students appear to appreciate the flexibility offered by the programs. Broader exposure of the SE students to more engineering faculty working on problems with sustainability themes would be of value to both the SE students and the College of Engineering.

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